The Suzaku Data Reduction Guide

–also known as the ABC Guide–

Version 1.2 – Processing version 1.1

Institute of Space and Astronautical Science (ISAS/JAXA)
and the
X-ray Astrophysics Laboratory
NASA/Goddard Space Flight Center

Copies of this guide are available in `html`, `postscript`and `pdf` formats.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

This document is meant as a guide and reference for scientists who are generally familiar with astronomical X-ray analysis and the *Suzaku* instruments and want to use *Suzaku* data to extract scientific results. General information on the *Suzaku* satellite may be obtained from the *Suzaku* Guest Observer Facility (GOF) page, `http://suzaku.gsfc.nasa.gov`. Readers who are not familiar with the *Suzaku* instruments may wish to read the technical appendix of the NASA Research Announcement (NRA), available at `http://suzaku.gsfc.nasa.gov/docs/suzaku/prop_tools/suzaku_td`.

This is only meant to be a brief guide to *Suzaku* data analysis. Unusual data modes, complex data reduction methods, and advanced data analysis techniques are outside its present scope but could be added as time progresses. The software needed for *Suzaku* data analysis is described in Chapter 2, including instructions for its downloading and installation. In Chapter 3, we explain the *Suzaku* data directory structure, coordinate systems, and file names and formats. Chapter 4 contains all the restrictions that apply to the current document. This chapter will be updated as frequently as necessary as we expect new calibration files, and changes in the processing at the beginning of the data distribution phase. In Chapter 5 and 6, we explain how to analyze data from the X–Ray Imaging Spectrometer (XIS) and Hard X–Ray Detector (HXD) and explain the issues linked to the background in both analysis. Acronyms used in this document are described in Appendix A. Useful email addresses and websites are given in Appendix B.

Chapter 2

Software

Suzaku data reduction is primarily performed using the `HEAsoft` package, which is described in detail at `http://heasarc.gsfc.nasa.gov/docs/software/lheasoft`. `HEAsoft` is a multimission collection of programs and scripts (frequently also called FTOOLS, for historical reasons), all using a similar interface which can be used both interactively and in scripts. A suite of new programs has been added to `HEAsoft` to support the *Suzaku* mission, collectively called the "*Suzaku* FTOOLS." Since *Suzaku* data files are in FITS format, other analysis suites (such as CIAO) can be used with *Suzaku* files to complete certain tasks. However, due to limited resources the *Suzaku* GOF will focus support on using `HEAsoft` to analyze *Suzaku* data and only support other tools as time permits. Users should have installed `HEAsoft` version 6.1.1 or later, including the *Suzaku* FTOOLS.

Suzaku data analysis will be supported on major Unix architectures, such as Linux, Solaris and OS X. `HEAsoft` runs on Windows in principle, but not yet as smoothly as on Unix. Therefore, *Suzaku* users are strongly suggested to use one of the supported Unix systems, listed on the `HEAsoft` website.

Suzaku FTOOLS will evolve rapidly in the early stages of the mission, hence a shorter release cycle will be required. In order to keep up with the rapid development cycle, we are planning to release the "*Suzaku* add-on" package on a shorter interval ($\sim$ months) than the complete `HEAsoft` . Users will be able to install the *Suzaku* FTOOLS on top of their current `HEAsoft`. All the software required to calibrate *Suzaku* data are written by the instrument teams and released as FTOOLS so that the latest calibration by the instrument teams are promptly made available to general *Suzaku* users. Also, *Suzaku* users are able to recalibrate their data using the FTOOLS when new calibration information is made available. Readers who are interested in how the *Suzaku* FTOOLS are developed and maintained can find more detailed explanations at the following page, as well as the complete *Suzaku* FTOOLS list at `http://suzaku.gsfc.nasa.gov/docs/suzaku/analysis/suzaku_ftools.html`.

2.1 XSELECT

`xselect` is a multi-mission program which has been widely used to analyze data from *ASCA*, *ROSAT*, *BeppoSAX*, *Einstein*, *Chandra* and other high energy missions. After passing through standard processing, *Suzaku* event files do not require any particular analysis software, since they comply with FITS event file standards. Nonetheless, the *Suzaku* GOF recommends `xselect` as a convenient and straightforward analysis tool. Therefore, in this document it is assumed readers will use `xselect` to extract *Suzaku* data into spectra, images, and lightcurves. The primary purpose of `xselect` is to provide a "shell" that translates simple commands (such as "extract image") into more complicated mission- or instrument-dependent FTOOLS commands. This guide, however, will not describe all the features of `xselect`. Users unfamiliar with `xselect` should read the `xselect` manual, available at `http://heasarc.gsfc.nasa.gov/docs/software/lheasoft/ftools/xselect/xselect.html`. The most important FTOOL used by `xselect`, `extractor` actually extracts the images, spectra, light curves or newly filtered event files from input event files. Users wishing to create scripts based on `xselect` commands will likely want to use `extractor` directly.

2.2 XANADU

XANADU is a mission-independent data analysis software package for high energy astrophysics which is normally distributed as part of the `HEAsoft` package. Currently XANADU includes XSPEC for spectral analysis, XIMAGE for image analysis, and XRONOS for timing analysis. *Suzaku* spectral, image, and timing analysis may be carried out within XANADU. In particular, the *Suzaku* GOF will fully support spectral analysis using XSPEC, and provide spectral response files (and/or response generators) with the XSPEC standard format. This guide assumes that the user is generally familiar with the XANADU package but if not, more information can be found at `http://heasarc.gsfc.nasa.gov/docs/xanadu/xanadu.html`.

2.3 Profit

Profit is a new spectral analysis tool with a graphical user interface, designed generally for high-resolution spectroscopy but with *Suzaku* in mind. *Profit* is in active development and the reader is directed to the web page, `http://heasarc.gsfc.nasa.gov/docs/software/profit/profit.html`, for download instructions and details of its current functionality. In its initial release, *Profit* can display *Suzaku* spectra, focusing in and out as desired. Emission lines in the spectrum can be labelled using atomic data from either the ATOMDB or XSTAR line lists. The user can also select individual emission lines and redisplay the data in velocity space to search for line broadening or a Doppler shift. *Profit* has some ability to fit spectra, although this is rudimentary compared to XSPEC which is recommended when performing measurements for publication. Despite this limitation, *Profit* may be useful as a “first-look” tool when examining *Suzaku* data, especially for users not familiar with X-ray spectroscopy.

Chapter 3

Suzaku Data Specifics and Conventions

This chapter describes the contents of *Suzaku* observation data set, including the directory structure, data files, and the format of those files. The *Suzaku* data structure is similar to previous X-ray missions, with small variations.

3.1 Directory and Data File Structure

The standard *Suzaku* "pipeline processing" products (encrypted for proprietary data) are available from the GSFC HEASARC archive at `http://suzaku.gsfc.nasa.gov/docs/suzaku/aehp_archive.html` or using the BROWSE system at `http://heasarc.gsfc.nasa.gov/docs/archive.html`. Users can also access the data at the ISAS DARTS site (for Japanese and European-based observers). Standard data formatting and calibration are carried out in the pipeline processing, and all *Suzaku* users should start scientific data analysis from the pipeline processing products.

3.1.1 Retrieving the data

This section is relevant for US PIs only

When the data are processed, the PI of the observation will receive a mail from the *Suzaku* GOF at GSFC giving the FTP location to access and download the data. For more information on the format of the location (presently ftp://legacy.gsfc.nasa.gov/suzaku/data/obs/M/NNNNNNNNN where M is a number indicating the type of target and NNNNNNNNN the sequence number of the data), please access the guide to the *Suzaku* archive at: `http://suzaku.gsfc.nasa.gov/docs/suzaku/aehp_archive.html`.

There are two options available for the download: FTP and `wget`.
To retrieve the data via FTP type:

```
ftp legacy.gsfc.nasa.gov
login:  anonymous
password : your_email_address@your_domain_address
ftp> cd suzaku/data/obs/M
ftp> binary
ftp> get NNNNNNNNN.tar.gz
ftp> quit
```

To retrieve the data via `wget`[1], type:

```
wget --passive-ftp -q -nH --cut-dirs=5 -r 10 -c -N -np \
--retr-symlinks ftp_address_received
```

where the `ftp_address_received` is the location mentioned above:
ftp://legacy.gsfc.nasa.gov/suzaku/data/obs/M/NNNNNNNNN.

Once retrieved, the data have to be decrypted using either PGP or GPG software and a perl script available at the website `http://heasarc.gsfc.nasa.gov/docs/cookbook/decrypt_data.pl`. General information on how to decrypt the data is available at `http://heasarc.gsfc.nasa.gov/docs/cookbook/decrypt.html`.

3.1.2 Organization of the data

All *Suzaku* data (including ground calibration and test data) have unique 9-digit observation numbers (*e.g.* 900000450) which is used as the name of the top level directory. Under this directory are a series of sub-directories, each of which carries a particular kind of data file, as explained below. All the data files are in the standard FITS format, although some output products are in Postscript, HTML, GIF or simple ASCII[2]. The subdirectories are:

auxil Auxiliary files not associated with a particular instrument, such as the spacecraft attitude (file named aeNNNNNNNNN.att – see Section 3.2 for an explanation of the name structure) and orbital data (file named aeNNNNNNNNN.orb). The most important of these is the "filter file" (with the suffix "mkf"), in which various satellite and instrumental parameters to be used for data screening are recorded as a function of time.

[1] wget is available at `http://www.gnu.org/software/wget/wget.html`

[2] In the early stage of the mission, some calibration files may be ASCII files but these will eventually be converted into FITS format.

log Log files from the pipeline processing.

hxd Data from the Hard X-ray Detector (HXD).

xis Data from the X-ray Imaging Spectrometers (XIS).

Within each of the two instrumental directories (`hxd, xis`) there are four subdirectories:

hk Instrumental housekeeping files containing information such as voltages, temperatures and other detector-specific data.

event_uf Second FITS Files (SFF) are unfiltered events files derived from the First FITS Files (FFF). FFF are effectively the telemetry data converted into FITS format

event_cl Cleaned events in this directory have gone through the standard cuts (grades, SAA and such) and they are in principle directly useful for analysis. However, users can re-run these cleaning processes (see Chapters 5 and 6 for more on the standard cuts applied).

products Output products from the pipeline, such as GIF images of the data and automatically generated lightcurves.

The filename conventions in each of these directories are instrument dependent, as described in the next section.

3.2 Filenames

The filenames (except for some log files) use the following general convention:

`aeXXXXXXXXXiii_N_mmmmmmmm_ll.ext.gz`

where

ae is short for *Astro-E2* the initial name of *Suzaku*.

XXXXXXXXX is the observation sequence number and is identical to the directory name.

iii is the instrument specification. This string is set as follows: hxd=HXD, xi[0-3]=XIS-[0-3]. xis is used for files common to all the XIS units. This string can be omitted in files under the `auxil` and `log` directories.

N ranges from 0 to 9 and indicates the RPT file number. The original telemetry file is divided into RPT files and more than one RPT can contribute to one observation. The value of 0 is used when the science file combines data from different RPT or if there is only one RPT file that contributes to that sequence. This number can be omitted in files under the `auxil` and `log` directories.

mmmmmmmm is the file identifier. The string distinguishes between files from the same instrument.

ll indicates the file level. For event files, the string can be "uf" or "cl" to indicate "unfiltered" or "cleaned" event files. It also can be "bg", "sk", "sr" , "gso", "pin", "wel" (`products` directory for both the XIS and HXD) or "wam" (`hk` directory for the HXD). The string can be omitted.

ext is the file extension. Currently can take the values: "evt" (event files), "gti" (good time interval), "hk" (house keeping), "ghf" (gain history file), "lc" (light curve), "pi" (pulse invariant), "hltm", "log", "com", "att" (attitude file), "cat", "ehk", "mkf", "orb", "tim","img", "gif".

For more informations on file names of the products of the pipeline processing, please refer to the documentation that can be found at `http://suzaku.gsfc.nasa.gov/docs/suzaku/aehp_data_analysis.html`.

3.3 *Suzaku* Coordinates

The XIS is an imaging instrument (unlike the HXD), and the coordinate values in XIS files indicate the pixel center positions. The XIS coordinate systems are described below:

Sky coordinates "X" and "Y" are used to describe the sky positions of the events relative to a celestial reference point. The "tangential" projection is used, and North is defined up (increasing Y), and East is left (decreasing X). "X" and "Y" columns are computed using attitude information.

Focal plane coordinates These are the event locations on the focal plane, which is common to the four (there are four XIS detectors) imaging instruments. "FOCX" and "FOCY" event file columns are used. The FOC coordinates differ from the Sky images in that the satellite attitude is not considered in the former. FOC images of the four instruments should match, as instrument misalignments are already taken into account.

Detector coordinates These give the physical positions of the pixels within each sensor. Misalignments between the sensors are not taken into account. The DET X and Y values take 1 to 1024 for XIS. The XIS DETX/Y pixels correspond to the actual

Type		Type	Minimum	Maximum	Origin	Unit
Sky	X/Y	Integer	1	1536	768.5	$0.0174'$
	ROLL	Real	0.0	360.0	–	degree
FOC	X/Y	Integer	1	1536	768.5	$0.0174'$
DET(XIS)		Integer	1	1024	512.5	0.024 mm
ACT	X/Y	Integer	0	1023	–	–
SEGMENT		Integer	0	3	–	–
RAWX(XIS)		Integer	0	255	–	–
RAWY(XIS)		Integer	0	1023	–	–

Table 3.1: Types of coordinates and coordinate related variables and their possible values

1024x1024 CCD pixels, and the DETX/Y pixel size is the same as the CCD physical pixel size. The DET images will give correct sky images of the objects (not mirrored images), except that attitude wobbling is not taken into account. Note that X-ray images focused by the mirrors and detected by the focal plane instruments will be the mirror images , which have to be flipped to be the actual images of celestial objects. Thus, the original look-down images are flipped (and rotated if necessary) so that the satellite +Y-axis direction will be the DETY direction.

ACT and RAW coordinates The ACT coordinates are used to tell actual pixel locations on the chip. Each XIS chip is composed of the four segments, and the RAW coordinates are the pixel locations on each segment . Note that the XIS-0 and XIS-3 installations on the baseplate are aligned, whereas XIS-1 and XIS-2 are 90 degrees rotated relative to them, in opposite directions respectively. Therefore the relation between ACT and DET coordinates is dependent on each XIS sensor.[3]

3.4 Photon Energies and Pulse-heights

All *Suzaku* instruments are energy-sensitive, and each event has a measured “Pulse Height Amplitude” (PHA). The PHA may be both position- and time-varying, depending upon the instrument. Therefore, a calculated “PHA Invariant” (PI) is also determined using the PHA in combination with the instrumental calibration and gain drift. In all cases, the PI columns should be used to extract energy spectra, or to produce energy-band selected images or light curves. For reference, the approximate relationship between “true” X-ray energy E and the event PI is shown below for each instrument. The exact relationship

[3] Conversion from the RAW to ACT coordinates is not straightforward, because of the particular order of the pixel read-out and possible use of the Window option.

between energy and PI is given in the second extension of the instrument response matrix file, or "RMF."

XIS The PI column name is "PI", which takes values from 0 to 4095. The PI vs. energy relationship is the following: E [eV] = 3.65×PI [channel].

HXD The "PI_SLOW" column (as opposed to "PI_FAST") which takes values from 0 to 4095, should be used for GSO spectral analysis. The PI vs. energy relationship is the following: E [keV] =2×(PI_SLOW + 0.5). For PIN spectral analysis, the "PI_PIN" column which takes values from 0 to 255, should be used. The value in this column is copied from the PI column of the triggered PIN, which is one of the PI_PIN0, PI_PIN1, PI_PIN2 or PI_PIN3. The PI vs. energy relationship is the following: E [keV] =0.375×(PI_PIN + 1.0).

3.5 Timing Information

The *Suzaku* event arrival time is represented by the "*Suzaku* time," which is defined as the elapsed time in seconds from the beginning of the year 2000 (January 1st, 00:00:00.000) in UTC (when TAI is 32 seconds ahead). There will always be a constant offset between TT and *Suzaku* time, and this is reflected in the time-related keywords. The event time resolution of each detector as follows:

XIS In the Normal observation modes (5x5, 3x3 or 2x2) without a Window option, the time resolution is 8 sec, corresponding to a single frame exposure. The event time assigned is the midpoint of the exposure frame. When the Window option is used, depending on its size, the time resolution will be 4 s (1/2 Window), 2 s (1/4 Window), or 1 s (1/8 Window). In Timing mode, the time resolution is 7.8125 ms, regardless of the number of lines to be combined (either 64, 128 or 256). Users should note that when combining a small number of lines, there could be a noticeable amount of cross-talk between one time bin and the next, due to the wings of the PSF. For example, 64 lines is only about 1.2 arcmin, so a fraction of the source counts will fall on the neighboring groups of 64 lines, and so be mis-time-tagged by +/-N times 7.8125 ms. For this reason, it may be safer to always use a grouping of 256 lines.

HXD Nominal time resolution is 61μs, which corresponds to the HXD_WPU_CLK_RATE_HK parameter = 1 (Fine). A higher time resolution, 30.5μs is possible by commands, in which case HXD_WPU_CLK_RATE will be 2 (Super-Fine), although this is not user-selectable at this time.

	5x5	3x3	2x2	Timing
Super-High	985	1971	3942	9381
High	475	949	1899	4528
Medium	221	441	883	2114
Low	29	58	116	292

Table 3.2: Telemetry limits (in events/s) in different XIS modes

3.6 *Suzaku* Telemetry

3.6.1 Data rates

The telemetry rate determines the data transfer rate from the onboard instruments to the Data Recorder. Being limited by the data storage and downlink capacity, the highest data rates may not be used all the time[4]. Basically, a combination of the following three telemetry rates will be used for observations; High rate (262 kbps), Medium rate (131 kbps), or Low rate (33 kbps)[5]. Among the 10 Gbit raw data per day, 4 Gbits will be taken between the contacts (contact passes) with High and Medium bitrates, and 6 Gbits will be taken after the contacts (remote pass) using Medium and Low bitrates.

3.6.2 Allocations

Although the maximum Data Recorder recording rate is limited by the telemetry rate for each bitrate, allocation of the telemetry to various instruments is variable. The XIS and HXD telemetry limits will be dependent on the bitrates.

3.6.3 Telemetry Limits

XIS The approximate XIS telemetry limits (events/s for four XIS combined) for different bitrates and observational modes will be the following:

XIS events are compressed on-board and actual telemetry limits may vary within $\sim \pm 40\%$ depending on the PHA values. Note that different XIS sensors may be operated using different modes and telemetry allocations.

[4]The amount of the data taken per day is mainly limited by the capacity of the Data Recorder (6 Gbits) and the downlink rate at Uchinoura Space Center (2 Gbits/ground contact). There will be 5 ground contacts per day separated by 90 minutes, so it is expected that usually 10 Gbits/day raw data will be taken.

[5]In addition, there is Super-High rate (524 kbps), which may not be allowed for general observations.

HXD The approximate HXD Well telemetry limits will be the following (in counts/s): Super-High=1150, High=550, Medium=250, and Low=30. This is based on the assumption that HXD will take 30% of the telemetry. Note that the Crab rate in the HXD is ~ 200 cts/s.

3.7 `xselect` Default Parameters

XSELECT behavior for each mission is determined by the mission database file, usually located at $FTOOLS/bin/xselect.mdb[6]. The *Suzaku* entries in the mission database files enable the following:

- Common for all the instruments
  - Default light curve bin is 16 sec
  - "extractor" is used to extract products
  - WMAP[7] is created as the spectral file header
  - Default image coordinates are Sky coordinates (X and Y)
  - Default WMAP coordinates are Detector coordinates (DETX and DETY)
  - Event file has one of the following names; ae*xis0*.*, ae*xis1*.*, ae*xis2*.*, ae*xis3*.*, or ae*hxd wel*.*
  - The filter file has the name ae*mkf*, and is in the directory ../auxil relative to the event file directories
- XIS
  - Default image binning is 8 (makes a 384×384 image)
  - Default WMAP binning is 4 (256×256 WMAP)
  - "RAWX' and "RAWY" coordinates are set to "ACTX" and "ACTY", so the "set image raw" command creates ACT coordinate images
  - Pixels in the WMAP outside of the selected region will have the value "-1"
  - Spawns "rbnpha" when saving a spectral file, and rebins by a factor of 2 to reduce the number of channels from 4096 to 2048 linearly
- HXD

[6] Users may specify their own mission database file with an environmental parameter XSELECT_MDB.

[7] WMAP is the part of the detector image from which the energy spectrum has been extracted, and will be used to create spectral responses by downstream FTOOLS.

- "PI_PIN' is the default energy column to make energy spectra (thus a PIN spectrum is the default). Users need to "set phaname PI_SLOW" to extract the GSO spectrum.
- The UNITID event column is used in lieu of standard X, Y, RAWX, RAWY and DETX of imaging instruments, so that the "sky" or "raw" images will be a pseudo-diagonal image of UNITID [8]
- The DET_TYPE event column is used in lieu of DETY, so that the WMAP is created with UNITID vs. DET_TYPE, which will be useful when creating ARFs and RMFs
- No binning for image and WMAP
- Spawns "rbnpha" when saving a spectral file, and rebins by a factor of 4 to reduce the number of channels from 4096 to 1024. For PIN, the number of original channels is 256, so users should answer "no" to this option when saving PIN spectra. The GSO response will be made with 1024 channels.

[8] For each HXD event, UNITID and DET_TYPE tells the Well unit-ID and the detector type. UNITID takes a value in the range of 0 to 15 corresponding to the 16 Well units. DET_TYPE = 0 corresponds to GSO, and 1 to 4 correspond to PIN0 to 3 respectively.

Chapter 4

The "README FIRST" of *Suzaku* data analysis

4.1 Introduction

This chapter, updated frequently, contains the details of the current status of the data analysis. Most of the same information (in a more condensed form) can be found at `http://suzaku.gsfc.nasa.gov/docs/suzaku/aehp_proc.html` or `http://www.astro.isas.jaxa.jp/suzaku/process`. Users are encouraged to contact us via the comment webpage at `http://heasarc.gsfc.nasa.gov/cgi-bin/Feedback`.

4.2 XIS

4.2.1 Contamination

In late November 2005, contamination in the optical path of each sensor became apparent. Spectra of celestial sources show that the contaminant is predominantly carbon. Monitoring of 1E 0102.2-7219 and RX J1856.5-3754 shows that the contamination is increasing at a different rate for each sensor, from less than 0.3 to 0.9mg cm^{-2} day^{-1} leading to a equivalent additional column density of C of 6×10^{18} cm^{-2} (as of April 2006; see Figure 4.1). There is some indication that the rate of accumulation has recently stopped increasing. Observations of the bright earth show that the contaminant is twice as thick at the center of the field of view than at the edge, a pattern that tracks the temperature distribution on the optical blocking filter (OBF). This suggests that the contaminant is on the spacecraft side of the OBF, rather than on the CCD detector surfaces. Recent studies suggest that the contaminant is DEHP ($C_{24}H_{38}O_4$, or C/O = 6 by number) although the XIS team is still investigating the material's exact composition.

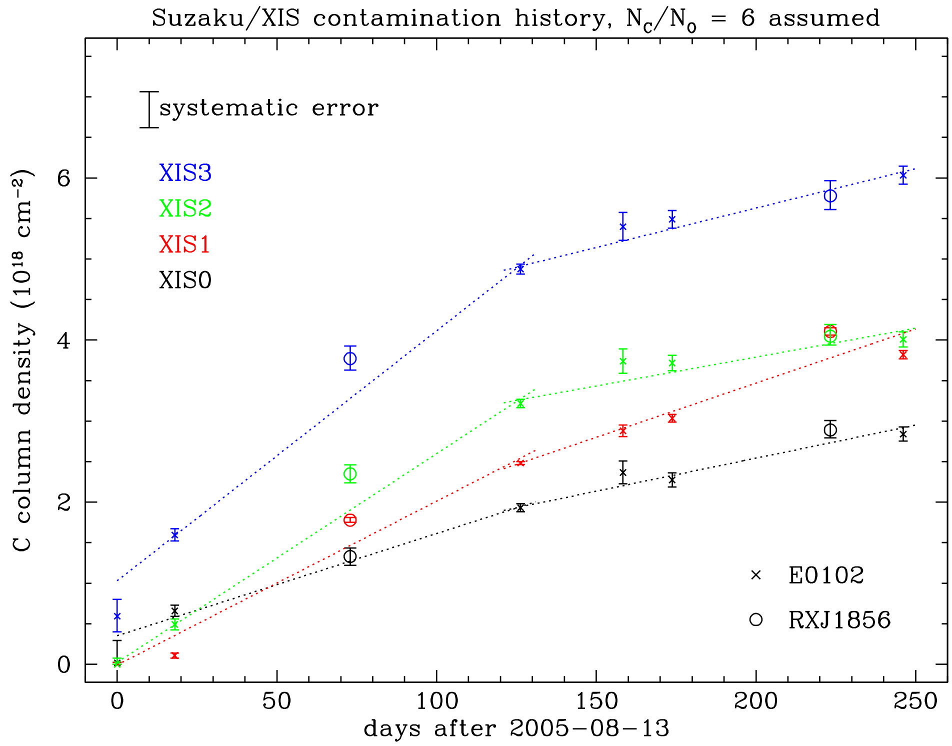

Figure 4.1: XIS contamination history as of April 2006

The XIS design allows the CCDs to be warmed to room temperature by reversing the current in the thermoelectric coolers. Independently, the OBF temperatures can be raised by activating heaters on the heatpipes that cool the sensor housings in which the filters are mounted. Either or both may help to reduce or reverse the contamination.

The newly released ARF generator simulation routine `xissimarfgen` contains the current information to take into account the contamination. `xissimarfgen` does have the broken line (as shown in the figure above) approximation of contamination built-in. Note, however, that the current calibration is probably inaccurate for more recent data (later than June 2006).

4.2.2 Imaging analysis

The software to produce exposure maps is not yet available

4.2.3 Timing modes

Currently timing mode data are not processed (nor distributed) and Fine timing assignment (< 8 s) is not done when window/burst options are used.

The software to apply barycentric corrections is not yet available

4.3 HXD

4.3.1 Background

The HXD background estimator is currently being tested by the instrument teams. At present the PIN background subtraction is accurate at the 5% level whereas the GSO background still has large uncertainties and GSO data should not yet be used for scientific purposes. Users should be aware of the fact that cosmic X-ray background is not included in the background models used by the HXD instrument team.

4.3.2 Energy range

The current response matrix cannot reproduce the Crab spectrum below 12 keV. The instrument team has been studying the energy scale of individual PIN diodes, in parallel with fine-tuning the response matrix but this study of the response is still ongoing.

4.3.3 Deadtime

The deadtime correction (necessary for accurate flux measurement) is done by measuring the ratio of pseudo-events that are issued by the on-board electronics to the true X-ray events. Since events occurring during dead time aren't recorded, the ratio gives the deadtime percentage. The task `hxtdtcor` is included in the current release, and can update the exposure keywords of spectral files using unscreened event files.

4.4 Cross calibration

There is currently a 5% normalization uncertainty in the HXD-XIS calibration.
Cen A was observed with RXTE and Swift and there are no noticeable differences with the Suzaku data. The agreement between XMM-Newton and the HXD is about 10%, although a power-law fit yields to a somewhat steeper slope.

4.5 Attitude Solution

There is currently a 30 arcsec level attitude wobble which is not currently in the attitude solution.

Chapter 5

XIS Data Analysis

5.1 Introduction

The XIS consists of four CCD detectors, three of which are "front-illuminated" (FI) and one "back-illuminated" (BI). The BI chip was a late addition to the XIS which increases the effective area of the entire system substantially at low ($< 1\,\mathrm{keV}$) energies with only a small decrease at higher energies. Although the detectors have seen significant improvements since the ASCA SIS, the data reduction is expected to be quite similar to that of ASCA SIS and Chandra ACIS.

5.2 Initial Processing

XIS data begins as part of the RPT telemetry downloaded from *Suzaku*, and is converted into a collection of FITS files by the `mk1stfits` routine at ISAS. `mk1stfits` does not reject any events or apply any calibration to the data but merely converts it to FITS files. Once the files have been processed through the pipeline (SFF), they are included in the standard data download in the directory "xis/event_uf".

The XIS `mk2ndfits` pipeline task is then run on the `mk1stfits` output to create filtered, calibrated output event files, lightcurves, and images, which are found in the directories "xis/event_cl" and "products". As the mission progresses, it is expected that these outputs will be the primary data for users. However, during the early stages of the mission we expect that the calibration applied by `mk2ndfits` will change frequently. The user should check the date of `mk2ndfits`, which is listed in the event file in the FITS keyword DATE. This can be compared again the list of calibration updates, found at `http://suzaku.gsfc.nasa.gov/docs/suzaku/aehp_proc.html`. If any substantial changes have occurred, the data should be reprocessed as needed, as described below. Users may want to create a new directory and run all the tasks from that new directory.

5.2.1 Calculating Sky Coordinates

`xiscoord` combines the position of the observed counts on the XIS detector with the orbit and attitude information to calculate the ACT, DEC, FOC and sky X/Y values for XIS event files. `xiscoord` uses either the attitude file assigned on the basis of the event input file name (the default), or fixed Euler angles if the parameter `attitude` is set to EULER. The RA and DEC used by the program can be either read from the header of the input event file or set manually.

Typically, users should not run this as it has been already run on the SFF file distributed in the event_uf directory. However, some user may want to rerun the command (especially when the attitude solution is improved and accuracy to better than 30 arcsec is necessary). In this case the command is:

```
xiscoord infile=filename_uf.evt.gz attitude=DEFAULT pointing=KEY \
outfile=xiscoord_outfile.fits
```

where
`infile` is the XIS event fits file name.
`attitude` indicates where to get the attitude information
`pointing` indicates where to read the RA and Dec – a pointing set to KEY reads them from the header of the input event file
`outfile` is the name of the output file created – see caveat below
The user should be aware of the following points: 1) For each XIS, the script requires a teldef file which is input by the option "xis0_teldef=". If this option is omitted from the command line, the file needs to be visible from the directory in which the task is run (soft links are OK).
2) When the attitude parameter is set to "Default", the code searches for a file named ***.att in the SAME directory as the input file. This can be bypassed by specifying the full path to the file on the command line.
3) We have found that `xiscoord` does not work properly on Linux 7.1 machines (the program fails to create an output file). Users are advised to run on a different platform if they encounter this problem.

5.2.2 Put Pixel Quality

`xisputpixelquality` runs on the output of `xiscoord`

In this case the command is:

```
xisputpixelquality infile=xiscoord_outfile.fits  badcolumn_file=CALDB_badcolum_file.fits \
calmask_file=CALDB_calmask_file.fits  outfile=xisputpixelquality_outfile.fits
```

where
`infile` is the XIS event fits file name (output from `xiscoord`)
`badcolumn_file` is the badcolumn file from CALDB
`calmask_file` is the calmask file from CALDB
`outfile` is the name of the output file created – see caveat below

5.2.3 Computing the PI for XIS events

As its name indicates, the `xispi` routine calculates the XIS PI and grades values from the PHAs. In addition to the input event file, the routine needs the CALDB files ae_xi[0-3]_makepi_[date].fits and the housekeeping file associated with the input event file. If the CALDB option is not set properly and the file has to be input manually, users should check which is the latest "makepi" file to be used. The command to run `xispi` is:

```
xispi infile=xiscoord_outfile.fits  trcor_caldbfile=ae_xi[0-3]_makepi_YYYYMMDD.fits \
cticor_caldbfile=ae_xi[0-3]_makepi_YYYYMMDD.fits \
grade_caldbfile=ae_xi[0-3]_makepi_YYYYMMDD.fits \
pha2pi_caldbfile=ae_xi[0-3]_makepi_YYYYMMDD.fits \
pha2pi_hkfile=HKFILE.fits outfile=xispi_outfile.fits
```

where
`infile` is the XIS event fits file name.
`trcor_caldbfile` is the CALDB file for charge trail parameters
`cticor_caldbfile` is the CALDB file for Input file for CTI parameters
`grade_caldbfile` is the CALDB file for the spth parameter (not used by default)
`pha2pi_caldbfile` is the CALDB file for the gain parameters
`pha2pi_hkfile` is the House Keeping file
`outfile` is the output file name.

5.3 User specific processing

Both bad pixel filtering and grade selections are done by the processing pipeline and implemented in the cleaned files distributed to the users.

5.3.1 Bad pixel filtering

The cleaning of hot and flickering pixels is done in `cleansis` and available as a standalone script at the GOF website `http://suzaku.gsfc.nasa.gov`. `cleansis` was originally written for analysis of the *ASCA* SIS data and removes hot and flickering pixels based on a

Poissonian analysis. It has since been adapted for work on SWIFT and *Suzaku* : This generalized version is available in all releases after 6.0.6 of `HEAsoft`. Users of an older version of `HEAsoft` can either update their version of `HEAsoft` or they will need to update their version of cleansis by downloading cleansis.f from the site mentioned above and replacing the copy in ftools/asca/src/cleansis in their source distribution of `HEAsoft`. Running hmake followed by hmake install in this directory will build the new version.

To run cleansis on Suzaku XIS event files type from the command line cleansis chipcol=SEGMENT, give the input and output filenames and use the default values of the remaining parameters.

5.3.2 Grade Filters

The GRADE column shows the event grade, which is determined from the distribution of pulse heights among the 5x5 (or 3x3 or 2x2) pixels. The standard spectral responses provided by the XIS team will assume GRADE 0,2,3,4, and 6. You may select only events with these grades (within the `xselect` task):
`select event ‘‘GRADE==0||GRADE==2||GRADE==3||GRADE==4||GRADE==6’’` or equivalently `filter grade‘‘0,2-4,6"`

5.4 Extracting Data within `xselect`

The primary tool for extracting data products (spectra, lightcurves, exposure maps) from XIS data is `xselect`, which is part of the general `HEAsoft` distribution. `xselect` can apply filters which select user-defined times, sky regions, or particular event flags. It then uses the filtered events to create a (binned) spectrum (as well as generating the necessary calibration files), a lightcurve, or an exposure map. Some basic parameters to be used for common data screening are in the filter file. The “select mkf” command is used to screen the output of the badpixel filtering and grade selections. The *Suzaku* instrument teams recommend the following cuts be applied within `xselect`.

```
select mkf  "SAA==0  && T_SAA> 436 && COR > 6 && ELV> 10 && DYE_ELV>20" \
mkf_name=MKF_filename  mkf_dir=/path-to-the-MKF-file/
```

Notes:
1) `mkf_name` and `mkf_dir` should be set automatically by `xselect` on read events.
2) `select mkf` command creates a time filter of good times. To actually filter the events, users must then issue the command “`extract events`”

Satellites, such as *Suzaku* launched into low-Earth orbit pass through the South Atlantic Anomaly (SAA). During a passage, the high particle flux makes the instruments unusable. The `mkf` keyword SAA is set to 0 when the satellite is **not** in the SAA and so the selection condition is SAA==0. Even when the satellite emerges from the SAA, the background is still high, the `mkf` keyword T_SAA indicates the amount of time since an SAA passage. For the XIS, T_SAA can be as low as 60 seconds. However, the HXD background stays high for much longer. The instrument teams have recommended adopting the same condition for both instruments, hence the cut of T_SAA>436 imposed on the XIS data. In addition to the SAA, there are still regions of high particle background where the geomagnetic rigidity is low. Data taken in regions of low rigidity (less than 6) should be discarded. We encourage the user to explore the effect of slightly different boundaries on their data.

The two last cuts are recommended by the instrument teams to reduce the contamination from the Earth's atmosphere. The first is applied to the elevation angle, `mkf` keyword ELV, the angle between the target and the Earth's limb. Only data with an elevation angle larger than 10 should be considered. The second concerns the elevation angle from the day Earth rim and helps reduce contamination in the Nitrogen and Oxygen lines from X-rays scattered on the Earth's atmosphere.
Users are encouraged to explore the effects of different values for all the cuts and selections described above on their own dataset by making lightcurves of `mkf` parameters.

5.4.1 Region Selection

Sky regions

It often happens that users want to extract light curves or energy spectra from some specific regions on the sky. Such region selection can be done on the "SKY" image displayed by ds9/saoimage; select a region and create a region file to use for the xselect "filter region" command. Region files should be created in `ds9` using the `ds9/funtools` format and equatorial J2000 coordinate system. Sky coordinates are the default image coordinates in xselect. After using other coordinates, enter `set image sky` to go back to sky coordinates.

Detector regions

Particular regions within a single detector may be selected using Detector coordinates. Use `set image det` command before extracting images. While Detector coordinates are defined so that all the XIS images have the same direction (§3.3), the four XIS sensors on the baseplate are rotated by 90° or 180° relative to each other. The ACT coordinates are the actual location on the CCD chip, which may be useful when investigating instrumental characteristics on particular chip positions (such as extracting the calibration source spectra). `set image raw` followed by `extract image` will extract XIS ACT images. XIS performance will be dependent on Segments, and particular Segments may be selected with the select event command. Events on Segment A, B, C and D have "SEGMENT" column value 0, 1, 2, 3 and 4 respectively.

5.5 Extracting a calibrated spectrum

The XIS and XRT instrument teams have released their first version of the `xissimarfgen` tool. The tool takes into account the contamination problem but at the time of this writing does not account for the attitude correction. You will find below hints and pointers on how to run the task. A description of the task is posted at `http://suzaku.gsfc.nasa.gov/docs/suzaku/analysis/xissimarfgen`.

The first thing to do before running `xissimarfgen` is to ensure that your `CALDB` variable is set properly because some of the hidden parameters of the task use the `CALDB` setup. The task can then be run by simply typing `xissimarfgen` and providing the input information requested by the program. A simple run would look like:

```
> xissimarfgen
xissimarfgen version 2006-08-02
Written by Y.ISHISAKI (TMU)
Instrument Name (XIS0,XIS1,XIS2,XIS3)[XIS0]
source mode (SKYFITS,DETFITS,J2000,SKYXY,DETXY,UNIFORM)[J2000]
source position R.A. (deg)[16.027162]
source position DEC. (deg)[-72.025293]
number of ARF regions[1]
region mode (SKYFITS,DETFITS,SKYREG,DETREG,etc)[DETREG]
region file #1[./src-det.reg]
output arf file #1[src.arf]
limit mode (ACCURACY,NUM_PHOTON)[MIXED]
number of photons for each energy bin[100000] 100000
calculation accuracy for each energy bin[0.005]
input pha file[src.pha]
XIS det-coordinates mask image file[ae_xi0_calmask_20051105.fits] none
input GTI file[e0102_init.fits] initial_event.fits
input attitude file[ae100014010.att] ae100014010.att
input rmf file[ae_xi0_20060213.rmf]
energy step file[estep-default.list]
```

Please note several potential pitfalls:

1) At this time, the first request for the source mode and position should **only** be given in J2000.
2) The program crashes if the image inputs have been rebinned. The input image

should be 1536x1536 for region_mode=SKYFITS, while it must be 1024x1024 for region_mode=DETFITS.
3) Users should specify the `REGION MODE` using preferentially the "region file" option. If one **must** use the `DETFITS` option, please note that the normalization is computed using only the non-zero pixels. One consequence is that the input image should **not** be the image defined by your source region, but a **mask** of that same region ie a file with **only** 1's for the pixels in the region selected and 0's outside. 4) The number of ARF regions is an option that allow you to compute up to 200 **different** ARF files running only once. If you specify "N" ARF regions, the program will ask you for N region modes, N region files and N output ARF file names. Please note that your parameter file keeps the highest number of regions in memory (along with the list of the region modes, names, and the ARF output names) so if you want to avoid generating a very long parameter file, you should run the code several times instead of using that option.
5) The CALDB option does **not** work for the mask image and the RMF input files. Users should input the file name by hand. For the moment (as the rmf generator code has not been released yet), the rmf input file should the CALDB file
6) The estep-default.list is an ascii file that contains the calculation steps, specified to take into account the different edges.

```
cat estep-default.list
# Emin Emax Ebin
0.2     16.00 0.01
2.101 2.399 0.002
2.501 2.799 0.002
3.101 3.299 0.002
11.801 11.999 0.002
13.601 13.799 0.002
14.201 14.499 0.002
```

Chapter 6

HXD Data Analysis

6.1 Introduction

The HXD significantly extends the spectral range of *Suzaku* (to 600 keV) and has the lowest background rate of any instrument ever operated in the 10-600 keV energy range. Please check the *Suzaku* HXD data analysis website at `http://suzaku.gsfc.nasa.gov/docs/suzaku/aehp_data_analysis.html` for updates, before attempting any analysis of HXD data.

The HXD is significantly different from the XIS. First, it does not have any imaging capability, although it does have a collimator which makes it act as a "light bucket." Second, it has two independent detector systems. These are the GSO/BGO phoswich counters and the PIN silicon diodes. The PIN diodes are sensitive below $\sim 60\,\mathrm{keV}$, while the GSO/BGO phoswich counters detect photons above $\sim 30\,\mathrm{keV}$. The energy resolution of the PIN diodes is $\sim 3.0\,\mathrm{keV}$, while the phoswich counters have a resolution of $7.6\sqrt{E}$ % (FWHM) where E is the photon energy in MeV. For more information about the HXD detector, please see the *Suzaku* Technical Description at `http://suzaku.gsfc.nasa.gov/docs/suzaku/prop_tools/suzaku_td`.

6.2 Initial Processing

HXD data begins as part of the RPT telemetry downloaded from *Suzaku*, and is immediately converted into a collection of FITS files by the `mk1stfits` routine at ISAS. `mk1stfits` does not reject any events or apply any calibration to the data, but merely converts it to FITS files. These files are included in the standard data download in the directory "hxd/event_uf".

The HXD `mk2ndfits` pipeline is then run on the `mk1stfits` output to create filtered, calibrated output event files, lightcurves, and images, which are found in the directories "hxd/event_cl" and "products". As the mission progresses, it is expected that this output will be the primary data for users. However, during the early stages of the mission the calibration applied by `mk2ndfits` may change rapidly. The user should check the date of `mk2ndfits`, which is listed in the event file in the FITS keyword DATE. This can be compared against the list of calibration updates, found at `http://suzaku.gsfc.nasa.gov/docs/suzaku/aehp_proc.html`. If any substantial changes have occurred, the data should be reprocessed as needed, as described below.

6.3 Processing description

For the HXD, the standard pipeline processing starts with an unfiltered file which contains events from both the GSO and PIN detector. This file contains "wel" in its filename and the DETNAM keyword has the value "WELL". We have described the processing steps (in the recommended order) below. We will describe first the processing for the PIN and GSO, and address later the processing for the WAM. **Please note that general users should not have to run these routines as the files delivered have already been processed with these routines.** The descriptions below are given more for completness than for general use by GOs.

6.3.1 Time Correction

The first step is to calculate the HXD event arrival-time correction. The arrival time of each true event time (in column TIME) is calculated from the HXD internal detector time value and other detector corrections. The computed time is then converted to *Suzaku* time coordinates using four separate methods (selected using the input parameter "time_convert_mode"). In addition, the tool `hxdtime` measures the actual time resolution of "TIME" during the observation. The standard way to run the `hxdtime` tool is to type:

```
hxdtime input_name=aeNNNhxd_M_wel_uf.evt create_name=aeNNNhxd_M_wel_uf2.evt \
leapsec_name=leapsec.fits hklist_name=aeNNNhxd_0.hk tim_filename=aeNNN.tim
```

where
`input_name` is the name of the original unfiltered event file in the hxd/event_uf directory
`create_name` is the name of the new (output) unfiltered event file name
`leapsec_name` is the name of the latest leap seconds file located in the CALDB (under mission "gen", under the filename leapsec_010905.fits) and in the `HEAsoft` refdata area (where a file is simply known as leapsec.fits, whose contents depends on the version of HEAsoft; in v6.1.1, it is identical to the leapsec_010905.fits)

`hklist_name` is the name of the HXD HK file found under hxd/hk
`tim_filename` is the name of the TIM file, found in auxil

Users may wish to confirm the following hidden parameters

read_iomode=create (a separate output file will be created) time_change=yes (TIME column will be updated in principle) time_convert_mode=4 (aste_ti2time function is used in calculation)

When a v1.1 processed file is re-processed with v1.2 software and calibration, the event file does not actually change. Therefore there is currently no reason to perform this step.

6.3.2 Gain History Generation

After calculating the corrected event time, the next step is to adjust the detector gain for both HXD detectors. This is done by fitting a calibration line present in the detector as a function of time. In the case of the GSO, an intrinsic Gd line is used. For the PIN diodes, the gain drift is not yet known, so the gain histogram routine here is simply a placeholder until better calibration can be done in flight.

The `hxdmkgainhist_gso` routine calculates the time variation of the PMT gain for both SLOW_PHA and FAST_PHA data by fitting the intrinsic Gd line peak appearing in the background energy spectra. The tool makes GTIs for each Well unit using the high voltage value of the PMTs, "HXD_HV_Wn_CAL" (where n=0,1,2,3) in HK FITS, and then separates these into several epochs with period set by the `exposure` parameter. The fit process is performed using XSPEC for SLOW_PHA and FAST_PHA, and summarized in the output fitlog file *gs_fitlog_name*.

In processing, gain correction is done using gain history files (one for the PIN, one for the GSO) generated from that sequence. Alternatively, the HXD team will provide long-term gain history files created from all observations. The latter is the more reliable method, and is recommended if an appropriate gain history file is already available in CALDB. However, if necessary, gain history files can be generated as follows.

```
hxdmkgainhist_gso input_name=aeNNNhxd_M_wel_uf2.evt \
    hk_name=aeNNNhxd_0.hk gso_gd_fitlog_name=aeNNNhxd_gso_gd_ghf.tbl \
    gso_511_fitlog_name=aeNNNhxd_gso_511_ghf.tbl \
    gso_152gd_fitlog_name=aeNNNhxd_gso_152gd_ghf.tbl process_id=aeNNN \
    exposure=1000000 \
```

where
`input_name` is the HXD_WEL_FITS file input name
`hk_name` is the HXD_HK_FITS file list name

`gso_fitlog_name` is the name of the GSO fit log (ASCII output) – input of `hxdmkgainhist`
`gso_511_fitlog_name` is the HXD GSO 511 keV fitlog file name (output file)
`gso_152gd_fitlog_name` is the HXD GSO 152 Gd fitlog file name (output file)
`process_id` is the identifier for the observation
`exposure` in s - the program attempts to determine the gain every N s of exposure.

It is recommended that, for this usage, the `exposure` keyword be set high enough that only one gain history record per output file is written. Even so, `hxdmkgainhist_gso` takes a considerable amount of time to run.
Warning If PGPLOT_TYPE is set to /xw it will (via `xspec`) generate plots on the user's computer screen and will leave 260 or so temporary files in a directory called aeNNN_hxdmkgainhist_tmp. Users should issue the command

```
setenv PGPLOT_TYPE /NULL
```

before running `hxdmkgainhist_gso`.

The `hxdmkgainhist_pin` routine calculates the gain history for the HXD WELL_PIN. As noted above, for the moment the routine simply creates an appropriately formatted output `pin_fitlog_name` file. Once the detector is better understood, this routine will be updated.

```
hxdmkgainhist_pin input_name=aeNNN_hxd_wel.uff \
hk_name=aeNNN\_hxd.hk pin_fitlog_name=aeNNN_pin_ghf.tbl process_id=aeNNN
```

where
`input_name` is the HXD WEL FITS file input name
`hk_name` is the HXD HK FITS file list name
`pin_fitlog_name` is the name of the PIN fit log (ASCII output) – input of `hxdmkgainhist`
`process_id` is the identifier for the observation

Once the gain drift for the two detector subsystems has been calculated, the `hxdmkgainhist` routine converts the output fitlog files created by the `hxdmkgainhist_gso` and `hxdmkgainhist_pin` routines into gain history FITS files.

```
hxdmkgainhist phaextractor_mode=n ghfwrite_mode=y \
   gti_time=S_TIME hxdmkgainhist_origin=YOURINST \
   input_name=aeNNNhxd_M_wel_uf2.evt pin_fitlog_name=aeNNNhxd_pin_ghf.tbl \
   gso_fitlog_name=@aeNNNhxd_gso_ghf.list valid_date=2005-08-15 \
   valid_time=11:00:00 pin_gainhist_name=aeNNNhxd_pin.ghf \
   gso_gainhist_name=aeNNNhxd_gso.ghf leapsec_name=leapsec.fits
```

where
`hxdmkgainhist_origin` is the name of the instrument
`input_name` is the HXD WEL FITS file input name
`pin_fitlog_name` is the name of the log output of `hxdmkgainhist_pin`
`gso_fitlog_name` see below
`valid_date` is the date of validity as stored in the CALDB database
`valid_time` is the time of validity as stored in the CALDB database
`pin_gainhist_name` is the name of the output PIN gain history file to be created
`gso_gainhist_name` s the name of the output GSO gain history file to be created
`leapsec_name` is the name of the leap-seconds file located under the `HEAsoft` refdata area

The file `aeNNNhxd_gso_ghf.list` is created using the command:

```
cat > aeNNNhxd_gso_ghf.list <<EOF
aeNNNhxd_gso_gd_ghf.tbl
aeNNNhxd_gso_511_ghf.tbl
aeNNNhxd_gso_152gd_ghf.tbl
EOF
```

Please note that the CALDB files provided will change over time. It is the responsibility of the user to check that the files that are used are indeed the latest in the CALDB. `hxdmkgainhist_origin`, `valid_date`, and `valid_time` parameters affect keywords in the output FITS gain history files, but do not affect their content.

6.3.3 Pulse Height Corrections

Once the gain drift has been measured, the (time) invariant event pulse-heights (PI) values can be determined. For the HXD, `hxdpi` calculates the HXD PI columns (PIN[0-3]_PI, SLOW_PI, FAST_PI) based on the relevant _PHA data, the gain history and other calibration data, such as non-linearity in the analog-to-digital conversion. The Gd edge effect is not included in SLOW/FAST_PI. The effect is included in the response matrix table for the GSO.

```
hxdpi input_name=aeNNN_hxd_wel.uff\
create_name=hxd_picorr_evt.fits hklist_name=@hk_list.dat\
pin_gainhist_name= ae_hxd_pinghf_date.fits\
gso_gainhist_name=ae_hxd_gsoghf_date.fits\
hxdpinlin_fname=CALDB/ae_hxd_pinlin_date.fits\
hxdgsolin_fname=CALDB/ae_hxd_gsolin_date.fits
```

where
`input_name` is the HXD FITS file input name

`hklist_name` is the HXD_HK_FITS file list name or input as @hk file list
`pin_gainhist_name` is the PIN gain history file either from CALDB or derived from the previous task
`gso_gainhist_name` is the GSO gain history file either from CALDB or derived from the previous task
`hxdpinlin_fname` is the name of CALDB file containing the PIN integrated non-linearity of ADC
`hxdgsolin_fname` is the name of CALDB file containing the GSO integrated non-linearity of ADC

Warning For `hxdpi`, the hidden parameter `read_iomode` is set to overwrite by default, so the relevant columns of the input file will be modified. Optionally, select read_iomode=create and specify an output file name.

In the above, the user can use either the gain history files created following the recipe in the previous section or the CALDB file appropriate for their observation. NB, if the CALDB files do not cover the time of your observation, the tool will run silently without updating the file content.

6.3.4 Calculating Event Grade

HXD event files have 5 grade columns filled by the `hxdgrade` routine. The first column is simply `GRADE_QUALTY` which stores the data quality. All events with a `GRADE_QUALTY` flag not equal to 0 should be ignored. The two next columns indicate the origin of the event. The column `GRADE_PMTTRG` is set to 1 for any PMT triggered event while the column `GRADE_PINTRG` is set for 1 for any PIN triggered event. Column `GRADE_PSDSEL` gives the GSO likelihood in the Slow Fast diagram while the fifth column `GRADE_HITPAT` gives the hit pattern grade.

```
 hxdgrade input_name=aeNNN_hxd_wel.uff   \
hxdgrade_psdsel_fname=CALDB/ae_hxd_gsopsd_20051116.fits \
hxdgrade_pinthres_fname=CALDB/ae_hxd_pinthr_20050916.fits
```

where
`input_name` is the HXD FITS file input name
`hxdgrade_psdsel_fname` is the name of CALDB file containing the GSO PSD selection criteria
`hxdgrade_pinthres_fname` is the name of CALDB file containing the PIN lower discriminator threshold

Warnings Just as for `hxdpi`, `hxdgrade` has an hidden parameter `read_iomode` set to overwrite by default, so the relevant columns of the input file are modified. Optionally, select read_iomode=create and specify an output file name.

6.4 WAM Processing

The HXD Wideband All-Sky Monitor (WAM) utilizes the BGO anti-coincidence detectors to create an all-sky monitor. Although from the same detector, these data are processed independently. There should be no need for the user to reprocess the data from the WAM (the HXD team will analyze the WAM data and make the results public) but we have included the description of the processing pipeline for completeness.

6.4.1 `hxdwamtime`

The `hxdwamtime` routine compute the HXD event arrival-time correction. The arrival time for events detected in the WAM is computed in a manner similar to the `hxdtime` routine, where the conversion to *Suzaku* time coordinate is done using one of four methods to be specified by the parameter `time_convert_mode`.

```
 hxdwamtime input_name=aeNNN_hxd_wam.fff  create_name=aeNNN_hxd_wam.uff \
hklist_name=@hk_list.dat leapsec_name=leapsec.fits tim_filename=aeNNN.tim
```

where
`input_name` is the HXD_WAM_FITS file name to archive the time correction
`created_name` is the HXD_WAM_FITS output name
`hklist_name` is the HXD_HK_FITS file list name or input as @hk file list
`leapsec_name` is the name of the leap-seconds file located under the `HEAsoft` refdata area
`tim_filename` is the name of the TIM file.

6.4.2 `hxdmkwamgainhist`

This routine produces a gain history file for the WAM FITS, where gain-correction factor is given as a function of time. It is determined by fitting the data of the 511 keV line, much as the gain histogram is calculated for the HXD GSO from the Gd line. The fitting results are recorded in a log file. The gain history file will be used as input for `hxdwampi`.

```
hxdmkwamgainhist input_name=aeNNN_hxd_wam.uff trn_fitlog_name=aeNNN_hxd_wam_fit.log \
trn_gainhist_name=aeNNN_hxd_wamghf.fits  leapsec_name=leapsec.fits
```

where
`input_name` is the HXD WAM FITS file name
`trn_fitlog_name` is the name of the log (ASCII output)
`trn_gainhist_name` is the name of the gain history file (output) to be used as input for `hxdwampi`
`leapsec_name` is the name of the leap-seconds file located under the HEADAS ref area

6.4.3 `hxdwampi`

The **`hxdwampi`** routine calculates the time-invariant pulse-height value for each HXD WAM event, which is stored in the TRN_PI column. By default, the input file is used as the output, although this can be modified by setting the create_name parameter. The gain drift is not corrected in the current **`hxdwampi`**, but instead is considered in the response matrix. The task expands the reduced PH table via HXD-DE on-board process. The setting is identified by the column "TRN_TBL_ID", which is defined in the caldb FITS file named "ae_hxd_wampht_YYYYMMDD.fits" (currently "ae_hxd_wampht_20050916.fits").

```
 hxdwampi input_name = aeNNN_hxd_wam.uff  hklist_name = @hk_list.dat\
 trn_bintbl_name =   CALDB/ae_hxd_wampht_20050916.fits \
trn_gainhist_name = aeNNN_hxd_wamghf.fits
```

where
`input_name` is the input HXD WAM file name
`hklist_name` is the HXD HK FITS file list name or input as @hk file list
`trn_bintbl_name` is the name of the CALDB file associated with the PH compression process
`trn_gainhist_name` is the file name of the gain history file output of hxdmkwamgainhist.

6.4.4 `hxdwamgrade`

This routine calculates the event grade for a WAM event, much as the **`hxdgrade`** tool does for a standard HXD event. As with the **`hxdwampi`** tool, by default the input event file is also used as the output file, simply modifying the QUALITY column.

```
hxdwamgrade input_name=aeNNN_hxd_wam.uff  hklist_name=aeNNNhxd_0.hk
```

where
`input_name` is the input HXD WAM file name
`hklist_name` is the name of the input HK file

6.4.5 hxdbsttime

Fill the "BST_FRZD_TM" keyword in the header of the BURST FITS.

```
hxdbsttime input_name=aeNNN_hxd_bst_0.fff create_name=aeNNN_hxd_bst_0.uff\
 hklist_name=@hk_list.dat  leapsec_name=leapsec.fits  tim_filename=aeNNN.tim
```

where
`input_name` is the HXD WAM FITS file name
`create_name` is the HXD WAM FITS output name
`hklist_name` is the HXD HK FITS file list name or input as @hk file list
`leapsec_name` is the name of the leap-seconds file located under the `HEAsoft` refdata area
`tim_filename` is the name of the TIM file.

6.5 Extracting Data

As described in Chapter 5, the primary tool for extracting data products (spectra, lightcurves, exposure maps) from HXD data is `xselect`. `xselect` can apply filters which select user-defined times, or particular event flags. It then uses the filtered events to create a (binned) spectrum (as well as generating the necessary calibration files), a lightcurve, or an exposure map. Some basic parameters to be used for common data screening are in the filter file. The `''select mkf''` command will be used to carry out filter file based data screening, by specifying boolean expression of the parameters and calculating corresponding Good Time Intervals (GTI). *Suzaku* GOF and instrument teams are currently working to determine recommended parameters and screening criteria.

6.5.1 Event Flag Selection & Separating PIN and GSO events

Note that "select event" creates new event files of the selected events, and the extract command afterwards will work on the new event files.

HXD event files have both GSO and PIN events (please note: HXD event files in the event_uf directory have both GSO and PIN events; those in even_cl directory are separated). An X-ray event can hit only a single detector (either GSO, PIN0, PIN1, PIN2 or PIN3) in a single Well-unit at a time, and the the UNIT ID and DET TYPE columns tell the unit ID and detector type for each event. To carry out a spectral analysis, GSO and PIN events have to be separated (spectral responses are completely different), where these events might be combined to make a light curve. All the GSO sensors are considered to have almost identical characteristics, so are the PIN detectors. Therefore events from the 16 GSO sensors can be combined to make GSO spectra; the same for 64 PIN sensors to make PIN energy spectra. To select only GSO events: `select event ‘‘DET_TYPE==0’’`, or, to select only PIN events: `select event ‘‘DET_TYPE==1"`. `hxdrti` ftool will fill this column.

```
select event ’’DET_TYPE==1’’
```

Users should note that GSO and PIN event selections are exclusive. Therefore, when extracting GSO and PIN energy spectra from the same event file, one needs to clear the select buffer after the first selection. There is an integer `GRADE` column which shows the legitimacy of the GSO events. For example, for spectral analysis, the HXD team may provide standard GSO responses which are valid only for some limited `GRADE` values; only events which have such `GRADE` values should be selected. On the other hand, for light curve analysis, the `GRADE` selection criterion may be loosened.

Particular Well units may be chosen with the select event command, specifying UNITID to use (from 0 to 15). This can be combined with the detector selection (GSO, PIN0, 1, 2, 3 or 4) using DET ID, as explained in section 4.2.4. For example, `select event ‘‘UNITID==0&&DET_TYPE==1’’` will select only PIN0 events from UNITID=0. Although HXD is not an imaging instrument, xselect can create HXD pseudo-images, which may have some use. For example, `set image det` will create a pseudo-image of `UNITID` vs. `DET TYPE 5` . This "image" tells the number of counts for each Detector on each Unit at a glance. Users may choose particular Units and Detectors graphically. The HXD Sky and Raw images will be a diagonal pseudo-image of `UNITID`, which tells number of counts for each `UNITID`, regardless of the Detector type (either GSO, PIN0, 1, 2, or 3). Click "cursor" and choose the "point" type selection on the left.

The file obtained through the above reprocessing steps still contains a mixture of PIN and GSO events. For further analyis, these must be separated, using the DET_TYPE column (0 for GSO events, 1 for PIN events). For users reprocessing an individual sequence, this is most conveniently done using xselect.

Given this, it is convenient to also apply a set of screening criteria and produce a cleaned event file for the PIN and a cleaned event file for the GSO. Here is an example:

```
$ xselect

                          **  XSELECT V2.4   **

> Enter session name >[xsel] hxd
 Setting plot device to /xw
hxd:SUZAKU > set datadir .

Setting data directory to ../hxd/v12/
```

```
Setting mkf directory to ../auxil/

hxd:SUZAKU > read events ae401038010hxd_1_wel_uf.evt

 Notes: XSELECT set up for      SUZAKU
 Time keyword is TIME       in units of s
 Default timing binsize =   16.000

Setting...
 Image  keywords   = UNITID     UNITID      with binning =    1
 WMAP   keywords   = UNITID     PIN_ID      with binning =    1
 Energy keyword   = PI_PIN                 with binning =    1

Getting Min and Max for Energy Column...
Got min and max for PI_PIN:     0    255

could not get minimum time resolution of the data read
MJDREF =  5.1544000742870E+04 with TIMESYS = TT
 Number of files read in:  1

******************** Observation Catalogue ********************

Data Directory is: ../hxd/v12/
HK Directory is: ../hxd/v12/


       OBJECT      DETNAM      DATE-OBS    TIME-OBS    DATE-END    TIME-END
      1 1RXS J21334 WELL        2006-04-29  06:50:50    2006-05-01  01:44:43

hxd:SUZAKU-HXD-WELL_PIN > filter mkf
> Boolean expression for filter file selection >[SAA==0] SAA_HXD==0 && \
T_SAA_HXD>436 && ELV>5 && ANG_DIST<1.5 && HXD_DTRATE<3 && \
AOCU_HK_CNT3_NML_P==1 && COR>8 && \
HXD_HV_W0_CAL>700 && HXD_HV_W1_CAL>700 && HXD_HV_W2_CAL>700 &&\
 HXD_HV_W3_CAL>700 && HXD_HV_T0_CAL>700 && HXD_HV_T1_CAL>700 &&\
  HXD_HV_T2_CAL>700 && HXD_HV_T3_CAL>700
PREFR keyword found in header, using prefr =   0.0
POSTFR keyword found in header, using postfr = 1.0
hxd:SUZAKU-HXD-WELL_PIN > filter column
> Enter filter on column(s) in the event file >[DET_TYPE=0:0] DET_TYPE=1:1
hxd:SUZAKU-HXD-WELL_PIN > ext events
extractor v4.67     11 Jul 2006
```

```
 No image X-axis TCRPX, set to 0
 No image Y-axis TCRPX, set to 0
 No image X-axis TCRVL, set to 0
 No image Y-axis TCRVL, set to 0
 No image X-axis TCDLT, set to 1
 No image Y-axis TCDLT, set to 1
 Doing file: ../hxd/v12/ae401038010hxd_1_wel_uf.evt
100% completed
   Total      Good    Bad: Region      Time     Phase     Grade     Cut
 14479114   55203     0      5836532         0         0   8587379 Writing events file
  55203 events written to the output file
================================================================================
   Grand Total      Good   Bad:  Region      Time     Phase     Grade    Cut
      14479114     55203              0   5836532         0         0   8587379
   in  65656.     seconds
hxd:SUZAKU-HXD-WELL_PIN > save events newpin.evt
Wrote events list to file newpin.evt
> Use filtered events as input data file ? >[no]
hxd:SUZAKU-HXD-WELL_PIN > exit no
```

The output, called newpin.evt, in this case, is similar to the hxd/event_cl/aeNNNhxd_0_pinno_cl.evt but with new calibration. However, a couple of keywords need to be modified. First, the DETNAM keyword should be changed to WELL_PIN; second, the TIMEDEL keyword should be created (usually with the value $6.1\text{x}10^{-5}$, or 61 microseconds - users should check the value in the event_cl directory version).

GSO event file should be similarly separated (with DET_TYPE=0:0) and modified.

Of the mkf selection criteria, some are required to select time intervals during which HXD is operating with the usual setting (HXD_HV_Wn_CAL>700, HXD_HV_Tn_CAL>700). AOCU_HK_CNT3_NML_P==1 means normal pointing operation; HXD_DTRATE<3 exclude intervals during which the data rate low, since that means telemetry is saturated just with background events. SAA_HXD==0 selects intervals during which Suzaku was outside the SAA (using a map of the SAA determined empirically by the HXD team). These criteria should not be changed.

The others are standard values but there is room for experimentation. T_SAA_HXD>500 - at least 500 s after SAA passages ANG_DIST<1.5 - pointing is within 1.5 arcmin of the mean. ELV>5 - elevation of target above Earth limb is at least 5 degrees COR>8 - geomagnetic cut-off rigidity is at least 8 GeV/c

In particular, it is possible to create your own Night Earth HXD data by changing ELV>5 with appropriate expressions involving ELV, DYE_ELV (elevation above the Sunlit limb of the Earth), and NTE_ELV (elevation above the night Earth).

6.6 Extracting a calibrated spectrum

6.6.1 Response Generation

Currently response files are only available through CALDB. There are two files for the PIN (one for a nominal XIS pointing and one for an HXD nominal pointing) and two files for the GSO (for the same pointing conditions). Users are invited to check regularly for updates.

6.6.2 Background Generation

Background event files for both GSO and PIN have not been finalized. There are currently three models available and the instrument team is still discussing on whether they will release all the models or wait to select the "best" of the three models. Here again, users are invited to check regularly for updates.

Appendix A

Acronyms

The following table lists acronyms used in this document.

Chapter	Acronym	Definition
	ADC	Analogue to Digital Converter
	ARF	Ancillary Response File
	ASCA	Advanced Satellite for Cosmology and Astrophysics
	ASCII	American Standard Code for Information Interchange
	ATOMDB	ATOMic DataBase
	BGO	Bismuth Germanate
	BI	Back-illuminated
	CALDB	CALibration DataBase
	CCD	Charge-Coupled Devices
	CIAO	Chandra Interactive Analysis of Observations
	Co-I	Co-investigator
	CXB	Cosmic X–ray Background
	DARTS	Data ARchive and Transmission System
	DEC	Declination
	DET	DETector (coordinates DETX and DETX)
	EEF	Encircled Energy Function
	FI	Front-illuminated
	FITS	Flexible Image Transport System
	FFF	First FITS Files
	FOC	FOCal plane (coordinates FOCX and FOCY)
	FTOOLS	FITS Tools
	FW	Filter Wheel (on XRS)
	FWHM	Full-Width at Half-Maximum
	GIF	Graphics Interchange Format
	GO	Guest Observer

Chapter	Acronym	Definition
	GOF	Guest Observer Facility
	GRB	Gamma-Ray Burst
	GSFC	Goddard Space Flight Center
	GSO	Gadolinium Silicate
	GTI	Good Time Interval
	HEA	High Energy Astrophysics
	HEASARC	High Energy Astrophysics Science Archive Research Center
	HK	House Keeping
	HPD	Half-Power Diameter
	HTML	HyperText Markup Language
	HXD	Hard X–Ray Detector
	ISAS	Institute of Space and Astronautical Science
	JAXA	Japan Aerospace Exploration Agency
	NRA	NASA Research Announcement
	NASA	National Aeronautics and Space Administration
	NXB	Non-X–ray Background
	OBF	Optical Blocking Filter
	OS	Operating System
	PDMP	Project Data Management Plan
	PHA	Pulse Height Amplitude
	PI	Principal Investigator
	PI	Pulse Invariant
	PIN	Positive Intrinsic Negative
	PMT	Photon Multiplier Tube
	QDE	Quantum Detection Efficiency
	RA	Right Ascension
	RDD	Residual Dark-current Distribution
	RMF	Redistribution Matrix File
	ROSAT	RÖntgen SATellite
	RPT	Raw Packet Telemetry
	RXTE	Rossi X–ray Timing Explorer
	SAA	South Atlantic Anomaly
	SAX	Satellite per Astronomia X
	S/C	Spacecraft
	SFF	Second FITS Files
	SIS	Solid-state Imaging Spectrometers
	SWG	Science Working Group
	TAI	Temps Atomique International
	TOO	Target Of Opportunity
	USC	Uchinoura Space Center
	UTC	Universal Time Coordinated

Chapter	Acronym	Definition
	WAM	Wideband All-sky Monitor
	WPU	Well Processing Unit
	XIS	X–Ray Imaging Spectrometer
	XMM	X–Ray Multi-Mirror Mission
	XRS	X–Ray Spectrometer
	XRT	X–Ray Telescope
	XRT-I	X–Ray Telescope for one of the four XIS detectors
	XRT-S	X–Ray Telescope for the XRS detector

Appendix B

Important Web/e-mail/postal addresses

Primary Suzaku Sites

Japan:
http://www.astro.isas.jaxa.jp/suzaku/
http://darts.isas.jaxa.jp/

US : http://suzaku.gsfc.nasa.gov/
ESA: http://www.rssd.esa.int/Astro-E2/

Questions:

The US GOF can be reached using the web form available at
http://suzaku.gsfc.nasa.gov/docs/suzaku/astroe_helpdesk.html

Tools:

Viewing	http://heasarc.gsfc.nasa.gov/Tools/Viewing.html
PIMMS	http://heasarc.gsfc.nasa.gov/docs/software/tools/pimms.html
MAKI	http://heasarc.gsfc.nasa.gov/Tools/maki/maki.html
XSPEC	http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec/index.html
WebPIMMS	http://heasarc.gsfc.nasa.gov/Tools/w3pimms.html
WebSPEC	http://heasarc.gsfc.nasa.gov/webspec/webspec.html
XSelect	http://heasarc.gsfc.nasa.gov/docs/software/lheasoft/ftools/xselect xselect.html